The Association Between Injury Occurrence, the Acute:Chronic Workload Ratio and Other Correlates in Division I Collegiate Soccer Athletes: A Retrospective Study

by

Carson Donnelly O'Neill LAT, ATC

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This thesis was presented

by

Carson Donnelly O'Neill

It was defended on

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and approved by

Mary Murray, EdD, LAT, ATC, Assistant Professor, Sports Medicine and Nutrition

Mita Lovalekar, MBBS, PhD, MPH, Associate Professor, Sports Medicine and Nutrition

Thesis Advisor: Katelyn Allison, PhD, ACSM EP-C, Associate Professor, Sports Medicine and Nutrition

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External workloads derived from global position systems (GPS) have recently become a common objective measurement tool for injury and monitoring. While there are many variables related to injury, their relationship with the acute:chronic workload ratio (ACWR) and injury has not been examined in the collegiate soccer population. The purpose of this study was to examine the association between injury occurrence, the ACWR and other correlates such as phase of season and player position throughout two competitive seasons in Division I collegiate soccer athletes. Thirty-three collegiate men's soccer players participated in the study (age: 19.67 ± 1.53 years, height: 69.94 ± 2.50 in, weight: 73.21 ± 5.30 kg). Separate statistical analyses were conducted to identify the relationships between injury occurrence, the ACWR, and the other respective correlates (α=0.05). No significant associations were observed when investigating ACWRs with both phase of season and player position. No significant findings were noted between injury occurrence and phases of the season. Although no significance was demonstrated between injury occurrence of any/all injuries among all 5 player positions, a statistically significant association was displayed between player position and non-contact injuries, p = 0.002, as well as practice injuries, $p < 0.001$ during the 2018 season. When assessing the effect of ACWR values on injury, a significant association was noted for any/all injuries, $\chi_2(1)$ = -1.494, p = 0.034, as well as non-contact injuries ($\chi_2(1)$ = -1.983, p = 0.041) and practice injuries ($\chi_2(1)$ = -2.877, p = 0.006). The results suggest that the ACWR does not seem to be significantly

influenced by phase of season and player position, however, a negative ‘U’-shaped association may be observed with injury occurrence where both low and high ACWRs increase the occurrence of injury. Furthermore, the lack of subjects in each player position may have contributed to the presence of a relationship with injury occurrence during only one season. Future studies should consider various subject populations and demographics, standardize the method of ACWR generation, and investigate injury as patterns of relationships among variables to better understand of the multifactorial nature injury.

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Preface

I would like to thank a number of significant individuals and parties for their contributions to the completion of this project. First, I would like to thank the University of Pittsburgh Sports Medicine department for giving me the opportunity to pursue this degree while working as a graduate assistant athletic trainer at the university.

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1.0 INTRODUCTION

When considering performance optimization and injury mitigation in elite athletics, sports performance teams and medical personnel have recently utilized technology to assess objective variables of measurement related to performance and injury. With teams recognizing that performance is directly linked to the health status of designated players, a drive towards the best preventative measures is made to achieve utmost success. Beyond the negative effects of a team's performance when affected by injury, substantial financial costs including medical expenses, revenue off sales, and roster additions are upended by the clubs adding even more of a burden to the organization.[6, 42, 62] Thus, finding a balance between providing enough challenging stimuli to optimize performance while also avoiding placing athletes at further risk of injury is particularly important.

The ability to predict and prevent injury is very appealing to sports performance and medical teams, however, due to the multifactorial determinants correlated with injury this is extremely difficult. By monitoring athletes, researchers can now quantify risk factors associated with injury and this has become a common trend in injury prevention measures among elite teams.[1, 111] In addition to athletic participation, emotional and lifestyle stressors have also been identified as risk factors of injury and may display a direct association to injury in cases. Because all sports involve distinctive internal and external demands and may display a direct association to injury in cases, sports performance teams must examine such stressors individually when attempting to deter vulnerability to the dynamic etiology of injury.[117]

Soccer at the elite level can be best described as an intermittent sport characterized by repeated bouts of high-intensity running followed by periods of rest or low-intensity running.[82, 86] During a competitive season of collegiate soccer, players are frequently required to play consecutive matches within a 72-hour period generating relatively high weekly workloads. Furthermore, the limited time between games tends to result in inadequate recovery. Numerous studies investigating several matches within a short period of time, commonly referred to as match congestion, have shown increased injury rates, specifically of muscular tissue, among teams playing two matches separated by 4 or fewer days when compared to those with 6 or more days.[10, 11, 33] On top of an extremely congested competitive schedule, collegiate athletes also need to balance academics in order to remain eligible for participation. The extreme physical and mental demand places the athlete's health in a susceptible continuum where failure may occur either physiologically or psychologically and has been recognized by international soccer bodies as a concern.[59]

According to the EUFA Elite Club Injury Study (ECIS), workloads are recognized as one of the most important risk factors associated to injury.[88] Workloads can be classified into two distinct groups; internal workloads and external workloads. Internal workloads are described as values derived from ratings of perceived exertion or heart rate and assess the perceptual or physiological response to stressors.[52] External training loads represent the physical work output by the individual and may include values such as total player load, duration, total distance covered, and accelerations/decelerations. In an editorial by Hulin,[69] the authors identify the primary focus of monitoring workloads not as a 'predictor' of injury but instead as a tool for identifying the acceptable level of injury risk where the probability of injuries among athletes is reduced and chance of success is augmented.

1.1 INJURY

1.1.1 EPIDEMIOLOGY OF INJURY IN SOCCER

As the technical and tactical aspects of soccer continue to evolve, physical demands continue to climb causing an increase in injury incidence over past several years. Previous studies have demonstrated an increase of 30-35% in running and sprinting distances over a seven year period.[9] In a prospective study collecting injury data over a 7-year period among 23 Union of European Football Association (UEFA) clubs, each player sustained an average of 2.0 injuries per season.[38] Further studies investigating English professional footballers have supported this clinical incidence displaying a value of 1.9 injuries per player.[76] Incidence of injury in soccer is commonly identified as the number of injuries occurring per hours of athletic exposure and ranges from 2.48 to 9.4 injuries/1000 hours of exposure.[37, 76, 116] Injury incidence has been recognized as higher in match play ranging from 8.7 to 65.9 injuries/1000 hours when compared to training at 1.37 to 6.84 injuries/1000 hours of exposure.[36, 37, 76, 116] One systematic review analyzing injury incidence in soccer displayed incidence to be 3.3 to 15.3 times higher during matches than training.[101]

The type of injury greatly affects prognosis and recovery in the soccer population. The most common injury types are considered to be strains, sprains, and contusions.[35, 38, 64, 76, 90, 115, 116] Muscle strains account for up to 41.2% of all injuries, followed by ligamentous sprains at 17.1% and blunt soft tissue contusions at 13.7%.[76] Although they tend to be considered major injuries, fractures have been shown to only represent a small percentage of all injuries.[38, 64, 115, 116] Due to the wide variety of forces associated with lower extremity injuries, most studies classify mechanism of injury into two types; acute traumatic injury or chronic overuse injury. Acute traumatic injuries account for a minimum of 60% of injuries while overuse injuries ranged from 27% to 40% of the remaining injuries.[35, 37, 76, 116] Recurring injuries made up 12 to 16.9% of all injuries. [37, 38, 76, 116] Walden et al. found that among all recurring injuries, nearly two thirds were a result of overuse injury.[116]

Studies suggest that 64.2 to 92% of injuries taking place in soccer occur to the lower extremity.[37, 38, 76] The thigh region has been identified as the most common lower extremity injury site ranging from 17 to 31.7% of all injuries. [10, 14, 27, 35, 38, 76, 115, 116] Other prevalent sites of injury include the knee, at roughly 14.6%; the ankle, at 13%; and the hip/groin, at 12.5% of all injuries.[14, 35, 64, 76, 90, 115, 116] Within the thigh region, the hamstrings are the most affected area, accounting for up to 39.5% of all muscle strains and 12 to 16.3% of all injuries.[27, 38, 76, 116] The hamstrings also tend to be the most frequently reinjured body part.[37]

1.1.2 RISK FACTORS OF INJURY

As stated previously, the multifactorial determinants of injury hinder the ability of health care professionals and sports performance teams from completely mitigating injury likelihood and subsequent burden. However, these known variables associated with injury can be identified as risk factors and should be investigated in further detail. By advancing our knowledge of modifiable injury risk factors, preventative programs can be augmented and help diminish the likelihood of musculoskeletal injury. Subsequently, the negative repercussions of injury including participation time lost, decline in team performance, and the associated financial burden can be reduced.

1.1.2.1 PREVIOUS INJURY

Previous incidence of injury has been recognized as one of the most influential risk factors associated to injury.[7, 40, 41, 60, 61] Although previous injury is classified as a non-modifiable risk factor, proper recognition of this risk factor may allow clinicians to identify those at risk and intervene with preventative measures. Hagglund et al.[61] portrayed that annual preseason evaluation of previously injured players could be of great benefit in reducing injury. Sustaining a muscular injury in the prior season has shown up to a 3-fold increase in injury rates when compared to uninjured players.[61] As stated previously, recurring injuries have been identified to range from 12 to 16.9% of all injuries among professional soccer players.[37, 38, 76, 116] When investigating injuries in Scandinavian elite soccer players, re-injury rates have totaled between 22 and 30% of all injuries.[59, 60, 115] Although no studies have further investigated the wide distribution between populations, this is suspected to be associated with greater medical care, including individualized rehabilitation among the top-tier teams in Europe. Regardless of medical support, recurrent injuries have been shown to display longer rehabilitation periods when compared to first time occurrences.[38, 115, 116]

Although most understand that previous injuries suggest an increased risk of damage to the same tissues, the increased risk of injury at other anatomic locations often goes unrecognized.[61] This is due to physiological reactions, compensatory movements, and the appendicular skeleton working as a kinetic chain. Modifications commonly seen associated with injury include symptomatic responses of tightness, muscle weakness, scar tissue formation, neuromuscular inhibition, and biomechanical alterations and may further predispose an athlete to injury.[22, 23, 61, 81, 98] Numerous studies in soccer and Australian football have identified an increase in injury rates of the quadriceps and calf by 68% to 91%, respectively, when a history of injury to other lower extremity muscle groups was present.[61, 99, 114]

1.1.2.2 MUSCULAR IMBALANCES

Hagglund et al.[61] suggested that specific limb preference in soccer players may result in muscle imbalances which subsequently can lead to a higher likelihood of injury. When comparing dominant and non-dominant legs among English soccer players, altered strength characteristics have been recognized.[103] This is observed when assessing the different biomechanical patterns and loads occurring bilaterally between the kicking leg and planting leg. Preventative exercises for the hamstrings conducted during preseason has been found to decrease the rate of hamstring injuries in soccer players, however, has not been validated among other muscle groups.[24] When assessing muscular imbalance by the way of eccentric asymmetries, imbalances ≥15% among the hamstrings as well as the ankle dorsal plantar flexors were considered predictors of injury.[44, 45]

1.1.2.3 AGE

Several studies have presented that as the athlete ages, the risk of musculoskeletal injury increases.[7, 60, 66, 114] Among all muscles, the hamstrings have been correlated the greatest with an increase in age and injury.[39, 44, 114] Although not as common, another study has observed 2-fold increase in calf injury rates.[61] Correspondingly, the incidence of calf strains has previously been identified as 0.32 injuries/1000 hours for young players (<22 years), 1.07 in the intermediate age group (22-30 years), and 1.89 for older players (>30 years).[37] When investigating injury incidence in training among different age groups, players aged >30 years have shown a statistically significant higher rate of injury at 1.63 injuries/1000 hours of exposure compared to those aged <22 years with a value of 1.19 injuries/1000 hours. In match play, results coincided, however, just at a substantially larger rate of 9.54 injuries/1000 hours compared to 6.26/1000 hours.[37]

While the research findings on the cause of injury susceptibility in older athletes is ambiguous, it has been suggested that the increased risk may partially be associated to age-related changes occurring ≥25 years old including increased body weight and loss of flexibility.[47] Even though age is a non-modifiable risk factor, the objective measures concomitant to age and injury can be adjusted through preventative methods.

1.1.2.4 PLAYER POSITION

The position of the soccer player has only recently been considered as a potential risk factor associated with injury due to the different physical demands of each position. Current studies have investigated the physical and technical requirements of positional groups.[17, 80] In the classification of wide players considered to be wingbacks and wingers, increased values of high-intensity running distances were noted compared to those of the central players. Among the central players including central midfielders and center backs, shorter distances were covered but more technical demands occurred including total passes.[17] Thus, one can suspect different injuries will occur based upon varying repetitive patterns and traits. Results from previous studies lean towards no significant effect of player position on injury occurrence.[27, 84, 90, 112] However, other studies have shown that goalkeepers have reduced injury rates of the four most injured muscle groups, including hamstrings, quadriceps, adductors, and calves, when compared to outfield playing positions.[18, 61, 100] When investigating muscle injury recurrences, one study among a French professional club displayed a slight increase of reinjury in forwards and defenders when compared with defenders and goalkeepers.[18] Furthermore, more current studies are beginning to display a trend of increased risk of injury in forwards.[3, 5, 19, 30, 84, 112] As this is a newly established risk factor, further research should investigate the association to injury.

1.1.2.5 FATIGUE

Fatigue has been widely researched as a risk factor of injury and can be broken down into different subtypes including that of physiological and perceptual nature.[48, 49, 87, 91, 110] When considering the physiological fatigue response, further classification is commonly made to differentiate between central and peripheral fatigue. Defined by Davis and colleagues,[28] central fatigue is a subset of fatigue in which there is a failure to maintain the required or expected force output associated to specific alterations in central nervous system (CNS) function. One study investigating homeostatic disturbances during strenuous exercise hypothesized that central fatigue may be produced by physiological factors such as insufficient oxygen delivery to the brain.[97] Aerobic conditioning interventions have been observed to subdue early onset fatigue associated with oxygen depletion to the brain through cardiovascular adaptations such as increased blood distribution efficiency, increased capillarization, and enhanced blood viscosity.[15]

Peripheral fatigue relates to the peripheral nervous system and musculature fatigue after exercise. As a result of strenuous activity, metabolic alterations to the peripheral structures occur ultimately expediting the time to fatigue. Changes such as increased levels of inorganic phosphates, lactate and hydrogen ions, and muscle glycogen depletion have all been associated with muscular fatigue.[2, 12, 43] Therefore, providing individualized strength, aerobic, and anaerobic conditioning may positively influence metabolic characteristics and function during exhaustive exercise and help counteract early onset fatigue and unintentional musculoskeletal injury risk. Fatigue related musculoskeletal injury has been noted to occur more commonly in games than trainings due to the higher intensity bouts and demands placed on the body.[38]

Specifically, studies have shown that there is an increasing tendency of injury as time progresses into the later minutes of both halves of the game,[37, 38, 48, 49, 65, 119] while others displayed just in the final portion of the game.[28, 29] This rise in injury rates was prevalent among all injury types including strains, sprains, and contusions.[38]

Fatigue has also been linked to the time of season and its subsequent effect on injury. In collegiate athletics, it has been found that preseason practices display an increased incidence rate when compared to in-season.[67] This has been believed to be associated with athletes beginning the season inadequately conditioned and unaccustomed to the demands of the sport, thus increasing susceptibility to fatigue. Another study displayed a higher incidence of overuse injuries during preseason practice suggested to be associated to the devotion to physical training with fewer matches.[38] As the competitive season advances, more games occur than the normal in the average acute period. This match congestion yields decreases recovery time for athletes which has shown to lead to an increase in injury incidence.[10, 33] Bengtsson et al.[11] identified that matches preceded by 6 or 7-10 days had a muscle injury rate about 20% lower than if they had ≤3 days. This can be associated with the fact that muscular fatigue has been subjectively and objectively reported to remain for up to 72 hours following a football match or similar physical training.[89, 95] Thus, the importance of monitoring athlete's workloads during periods of dense match congestion allows coaches, sports scientists, and the sports medicine staff to recognize injury risk and intervene with training periodization and proper recovery before the athlete's health becomes compromised.

Another benefit to enhancing musculoskeletal and physiological characteristics may be a decrease in perceived exertion during exercise. One systematic review investigated the effect of greater perceptual responses when athletes are placed in 11 vs. 11 game simulations and displayed results of higher levels of mental fatigue through perceived exertion among numerous studies.[107] This mental fatigue was hypothesized to be associated with deterioration of technical qualities and decision making.[8, 108, 113] Thus, it has been suspected that with altered decision making, an athletes likelihood of injury increases. The psychological pressures placed on athletes has also been considered when investigating mental fatigue linked to the demands of the game. When considering the elite collegiate population, many strive to reach the professional ranks only exposing them to greater levels of stress as a student-athlete. One study identified the need to find a proper balance between match and training sessions along with school education among elite young soccer players.[101] Furthermore, Ekstrand et al[39] presented the topic of how mental burnout can increase the risk of injury in periods of the season with many matches.

1.2 ACUTE:CHRONIC WORKLOAD RATIO

1.2.1 DEFINITION OF THE ACUTE:CHRONIC WORKLOAD RATIO

The acute:chronic workload ratio (ACWR), also referred to as the ‘training-stress balance’ or the ‘fitness-fatigue model’, is derived from two distinct values of workload.[53, 92] The acute workload, corresponding to a state of ‘fatigue’, is the value composed of the absolute workload performed over a 1-week period. The chronic workload, commonly referred to a representation of ‘fitness’, is a relative 4-week average of the participant’s workload.[85, 92] Ratio parameters have been noted to vary in respect to the chronic workload which ranges from 2-, to 3-, to 4-week periods. Due to most studies presenting an at ACWR at 1:4 weeks or 7:28 days, this study will follow the same methodological considerations. Commonly, this workload derived ratio has been shown to display two clear themes; (1) sharp increases in the acute workload, producing a larger ACWR, is associated with injury in the current workload week or subsequent week, and (2) high chronic workloads may mitigate injury risk by offering a protective effect.[52, 54, 109]

1.2.2 ACWR AND INJURY

Athletes with inconsistent training programs, such as weeks of under- or over-training, may be subject to large relative changes in their workload ultimately increasing their risk of injury. These large changes, also known as “spikes” or “troughs”, identify the abrupt variability within the athletes’ training regimen. Proposed in the International Olympic Committee’s 2016 consensus statement, large absolute workloads including acute weekly workloads, week-to-week changes, and cumulated workloads increase the risk of injury.[109] Relatively high ACWRs as a result of large weekly workload changes, in particular >1.5, demonstrate the same effect on injury risk.[88, 92, 109] Elite rugby players displayed up to a 10-fold increase in injury risk when they were subjected to a workload classified as ~twofold greater than what they were accustomed to.[73] A ‘U’-shaped relationship between workload and injury presented by Gabbett demonstrated that both inadequate and excessive workloads are associated with injury.[52] Similar findings in regard to overtraining and undertraining have been identified in sports such as rugby, baseball, and cricket.[25, 31, 83]

1.2.3 ACWR FOR INJURY PREVENTION AND PERFORMANCE OPTIMIZATION

Although the aforementioned discussion on “spikes” in workload are a concern for increased injury risk, they may be suggested at times when attempting to elicit greater physiological adaptations in hopes to enhance performance.[53] The SAID principle, which is an acronym for specific adaptations to imposed demands, seems to relate directly to this belief. In select studies, high chronic workloads have been shown to provide resistance to injury during moderate-low through moderate-high (0.85-1.35) ACWRs.[54, 70, 73] The workload-injury paradox states that higher chronic workload protects against injury when acute workload is similar to chronic workload.[73] To optimally prepare for the demands of competition, athletes must maintain or increase their acute workload so that their ‘fitness’ or chronic workload is enough to overcome the current demands generating fatigue.[52]

1.3 RESEARCH PROBLEM

Injuries place a large burden on activities of daily living throughout the general population, however, the majority of incidences annually reported occur as the result of athletic-related events. As the sports industry is ever-growing, scientists and clinicians continually advance the best methods in athlete monitoring, prevention, and care in attempt to reduce injury and subsequent burden. Global positioning systems (GPS) and wearable accelerometers have become a new tool in which the sports performance team can analyze and monitor individual workloads in a team setting.[51, 55, 56, 68, 72, 73] To our knowledge, no research has investigated if ACWRs derived from portable accelerometers are associated with injury occurrence and player position in collegiate soccer athletes. Therefore, we investigated whether there is an association among ACWRs calculated by weekly player loads, injury occurrence, and player position.

1.4 STUDY PURPOSE

The purpose of this observational, retrospective cohort study was to examine the association between injury occurrence, the acute:chronic workload ratio and other correlates throughout two competitive seasons in Division I collegiate soccer athletes.

1.5 SPECIFIC AIMS/HYPOTHESIS

Specific Aim 1: To examine the ACWR throughout phases of the competitive season.

Hypothesis 1: It is hypothesized that the ACWR will vary throughout phases of the competitive season.

Specific Aim 2: To examine the association between ACWR and athlete position.

Hypothesis 2: It is hypothesized that ACWR will vary by athlete position.

Specific Aim 3: To examine injury occurrence during phases of the competitive season.

Hypothesis 3: It is hypothesized that injury occurrence will vary by phases of the season.

Specific Aim 4: To examine the association between injury occurrence and athlete position.

Hypothesis 4: It is hypothesized that injury occurrence will vary by athlete position.

Specific Aim 5: To examine the association between ACWR and injury occurrence.

Hypothesis 5: It is hypothesized that a greater ACWR will increase the likelihood of injury.

1.6 STUDY SIGNIFICANCE

The outcomes of this study will be important for injury risk mitigation and performance optimization in soccer athletes. Particularly, they will contribute knowledge to the existing research on injury risk and acute:chronic workload ratios. Identifying an association between injury risk and ACWRs can establish a plausible consideration when discussing modifications as preventative methods. Therefore, if significant relationships are noted, injury can be mitigated, and performance optimized with proper periodization adjustments.

2.0 METHODOLOGY

2.1 EXPERIMENTAL DESIGN

The study utilized an observational, retrospective cohort design. A cohort study design was chosen to examine the association between injury occurrence, the ACWR, and other correlates throughout two competitive seasons in Division I collegiate soccer athletes. Although this study design may provide association between the predictor and outcome variables, results will be interpreted with caution as association does not necessarily mean causation.

2.1.1 DEPENDENT VARIABLES

The dependent variables for this study included individual player ACWRs derived from wearable accelerometer/GPS units along with injury occurrence throughout the course of two seasons. Injury occurrence was further investigated to identify the date of injury, type of injury (contact vs. non-contact), and setting of injury (game vs. practice).

2.1.2 INDEPENDENT VARIABLES

The independent variables for this study included the position of the participants and phases of the season in relation to their workloads and injury occurrence.

2.2 SUBJECTS

2.2.1 SUBJECT RECRUITMENT

Subjects included active male collegiate soccer players who were members of the Division I men's soccer program at the University of Pittsburgh over the course of two competitive seasons (Fall 2018 and Fall 2019). Each competitive season was split into two distinct phases: 1st half (early August to late September/early October), and 2nd half (late September/early October to early-mid November). The 1st half of the season lasted 47.5 ± 4.949 days while the 2nd half of the season was 48.5 ± 4.949 days. As the primary investigator was the current athletic trainer with the men's soccer team at the University of Pittsburgh, access to all data was readily available through the team's external workload monitoring devices and medical records. The study was approved by the Institutional Review Board (IRB) at the University of Pittsburgh.

2.2.2 INCLUSION CRITERIA

Subjects were included into the study by being active field players for the Division I men's soccer program at the University of Pittsburgh. Field players consisted of defenders, midfielders, and forwards and were further broken down into specific positional classifications due to different demands seen among various positions. Defenders were apportioned into centerbacks (CB) and wingbacks (WB), midfielders into central midfielders (CM) and wingers (W), and forwards (F) remained as one group. Subjects were classified into their respective group based on it being their most consistent position knowing changes may occur at times in the season. All subjects had to be screened prior to their first season through the university's standardized pre-participation physical exam to rule out any musculoskeletal or cardiorespiratory pathology that would exclude them from participation at the collegiate level.

2.2.3 EXCLUSION CRITERIA

All goalkeepers on the university team's roster over the 2-year analysis were excluded from the study due to the club not mandating GPS and accelerometer usage during team events over the whole first season and part of the second season. Furthermore, the position of goalkeeper entails much different variables of consideration when assessing player loads, thus, values are pertaining to different measures. To further extend the criteria to meet study inclusion, all subjects that sustained injuries occurring at a point in the season where they did not return to participation for a minimum of 4 weeks had any remaining data excluded from analysis.

2.3 INSTRUMENTATION

2.3.1 CATAPULT OPTIMEYE S5

All players were provided an individually labeled portable accelerometer (Catapult OptimEye S5, Catapult Innovations, Team Sport 5.0, Melbourne, Australia) at the beginning of their collegiate career. These wearable devices were shown to display excellent intra-device reliability and were actively worn centrally between both scapula within a company-made sports bra for all competitive sessions including practices and games.[96] Data from each accelerometer was recorded at a sampling frequency of 100 Hz and was further downloaded from each device at the conclusion of each day using the manufacturer's software.

Figure 1 Catapult OptimEye S5

2.4 TESTING PROCEDURES

2.4.1 DAILY IN-SEASON CATAPULT MONITORING

All workload data was calculated individually as a daily total PlayerLoad (PL) from every competitive season training session and match, including preseason exhibitions and competitive matches. The weekly PL corresponded to the sum of the workload accumulated from all training sessions and matches in that designated week. In an attempt to provide consistency and avoid inter-device variability suggested in past studies, each player was provided with their own individually labeled device for their entire athletic career.[96]

2.4.2 IN-SEASON INJURY LOG

Injuries were monitored over the course of the two seasons using an injury log created by the team's sports medicine staff. Injuries were classified as any musculoskeletal ailment that resulted in participation days lost. Participation days consisted of both practices and games during the duration of the competitive season. The injury log was broken down into monthly participation columns to identify burden placed on the team at different stages in the season. Injuries logged also contained pertinent information regarding the date and diagnosis of the injury for purpose of further analysis.

2.4.2.1 DEFINITION OF INJURY

As the definition of injury can be extremely subjective, a standard definition and set criteria was established for the purpose of this study. In correspondence to previous studies while conforming to the consensus, an injury was best defined as any time-loss injury that subsequently resulted in a player being unable to complete full training or missing match time.[46, 71, 73, 79, 93] This involved all injuries sustained including both the upper and lower extremity over the course of the two competitive seasons. The mechanism of injury in which the subject sustained the injury was classified as either being contact or non-contact in nature and the injury setting as either game or practice.

2.5 DATA REDUCTION

All ACWR data was investigated individually using a week-by-week analysis. Acute workloads were formulated as the accumulative sum of the participant's daily PlayerLoad in the respective week, while chronic workloads were identified as a relative 4-week average of the participant's workload. ACWRs were calculated by weekly at 1:4 weeks or 7:28 days. Variables of interest being assessed over the course of the competitive seasons include PlayerLoad, player position, injury occurrence, injury date, and injury type (contact, non-contact, game, practice). PlayerLoad, displayed in Equation 1, is an arbitrary unit of measurement formulated by Catapult Innovations software defined as an "instantaneous rate of change of acceleration divided by a scaling factor", commonly known as 'jerk' in physics.[96] Quantifying movement intensity by using tri-planar accelerometers allows PlayerLoad to be calculated as follows:

Equation 1 PlayerLoad Formulated by Catapult Innovations

$$PlayerLoad = \frac{\sqrt{(a_{y(t)} - a_{y(t-1)})^2 + (a_{x(t)} - a_{x(t-1)})^2 + (a_{z(t)} - a_{z(t-1)})^2}}{100}$$

where a_y is forward (anterior-posterior) acceleration, a_x is sideways (medial-lateral) acceleration, and a_z is vertical acceleration.

2.6 STATISTICAL ANALYSIS

Catapult Optimeye S5 global positioning system (GPS) and accelerometers were used to track external workload variables during all participation events. An injury log was completed daily by sports medicine staff to identify participation days missed. Participation events were identified as both practices and games throughout the length of the competitive season. Normality was assessed using Shapiro-Wilk tests. Descriptive statistics were calculated for all variables (mean, standard deviation, median, inter-quartile range, proportion, as appropriate). Data analysis was conducted using IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.

Specific Aim 1: As data was not normally distributed, a Mann-Whitney U-test was conducted to assess the association between ACWR and phases of the season (1^{st} and 2^{nd} half of the season). A one-way ANOVA was conducted to assess the differences in the ACWR between phases across seasons.

Specific Aim 2: As data was not normally distributed, a Kruskal-Wallis test was conducted to examine the association between ACWR and athlete position identified as 5 different groups (CB, WB, CM, W, F).

Specific Aim 3: McNemar tests (exact versions) were conducted to examine the association between injury occurrence (yes/no) and phases of the season (1^{st} and 2^{nd} half of the season).

Specific Aim 4: Fisher's exact tests were conducted to examine the association between injury occurrence (yes/no) and athlete position identified as the same 5 groups listed above.

Specific Aim 5: To investigate specific aim four, the primary aim of the study, a binary logistic regression will be conducted. The outcome variable will be injury occurrence (yes/no) and the predictor variable will be ACWR measured at each week for the duration of the study.

Statistical significance was set *a priori* at $\alpha = 0.05$, two-sided.

3.0 RESULTS

3.1 SUBJECTS

A total of 33 collegiate men's soccer players aged 18-23 (mean ± standard deviation: 19.67 ± 1.53) years old met the required inclusion criteria for the study over the two competitive seasons outlined in the methods. Subject demographics are displayed in Table 1, Table 2, and Table 3.

Table 1 Subject Demographics: Age, Height, Weight

	N	Mean ± SD		Median	IQR (1st Q, 3rd Q)	
Age (years)	33	19.67	1.53	19.00	18.00	21.00
Height (in)	33	69.94	2.50	70.00	68.00	71.00
Weight (kg)	33	73.21	5.30	73.48	69.40	78.02

N = # of Subjects

Table 2 Subject Demographics: Player Position Frequency

Position	Subject Frequency
CB	8/33 = 24.2%
CM	8/33 = 24.2%
F	4/33 = 12.1%
W	7/33 = 21.2%
WB	6/33 = 18.2%
Total	33/33 = 100.0%

CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback

Table 3 Subject Demographics: Player Position Frequency by Season

Position	2018 Subject Frequency	2019 Subject Frequency
CB	5/22 = 22.7%	4/23 = 17.4%
CM	5/22 = 22.7%	6/23 = 26.1%
F	2/22 = 9.1%	3/23 = 13.0%
W	5/22 = 22.7%	6/23 = 26.1%
WB	5/22 = 22.7%	4/23 = 17.4%
Total	22/22 = 100.0%	23/23 = 100.0%

CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback

3.2 FREQUENCY DISTRIBUTION OF INJURIES

Over the course of the two seasons, a total of 40 injuries resulted in time lost from participation including practice and games. Injury classification frequencies in relation to season and player position are displayed in Figure 2, Figure 3, and Figure 4.

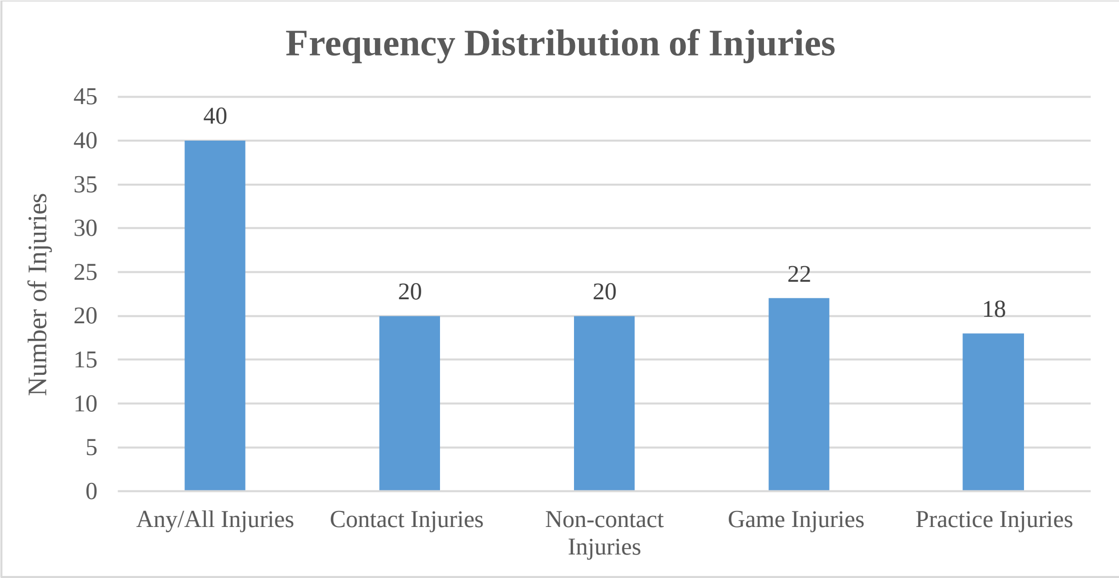

Figure 2 Frequency Distribution of Injuries over Two Seasons

Number of Any/All Injuries = Number of Contact Injuries + Number of Non-contact Injuries
Number of Any/All Injuries = Number of Game Injuries + Number of Practice Injuries

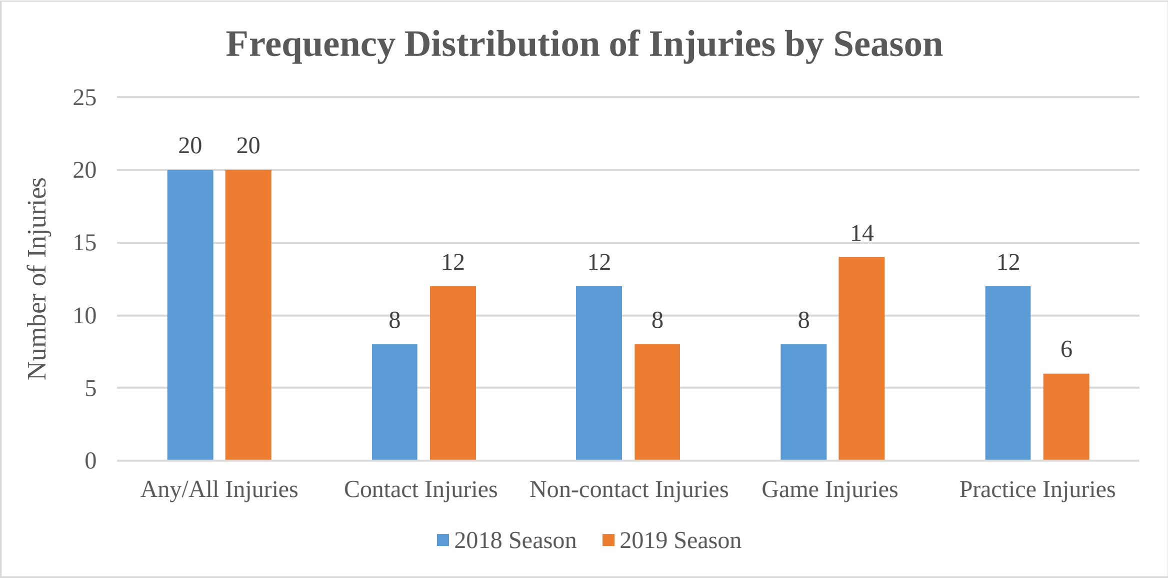

Figure 3 Frequency Distribution of Injuries by Season

Number of Any/All Injuries = Number of Contact Injuries + Number of Non-contact Injuries
Number of Any/All Injuries = Number of Game Injuries + Number of Practice Injuries

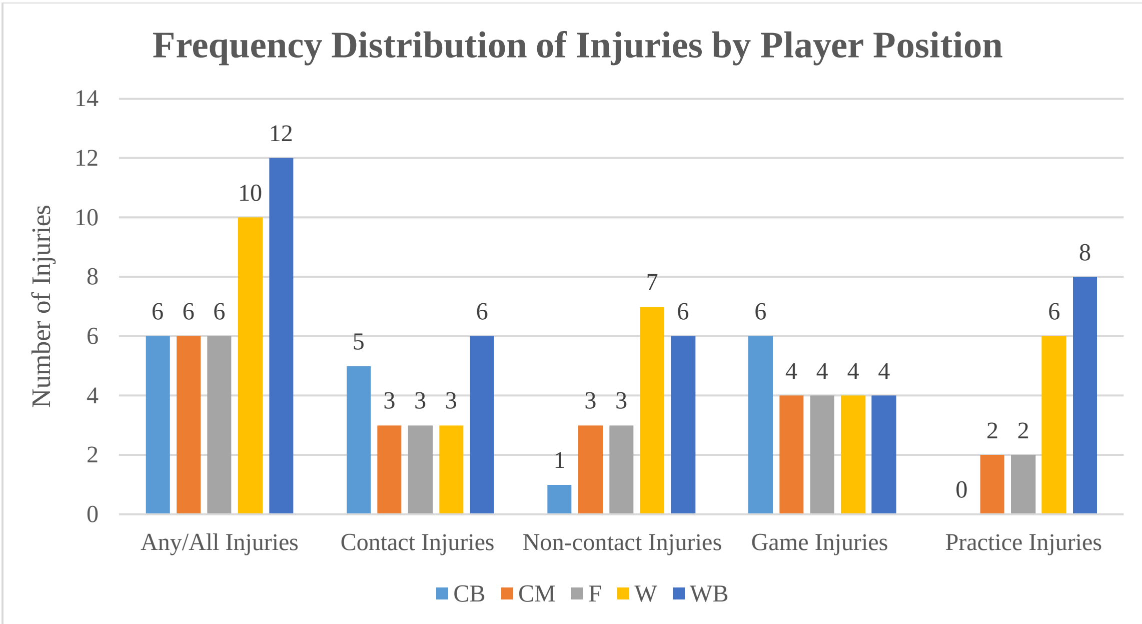

Figure 4 Frequency Distribution of Injuries by Player Position

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Number of Any/All Injuries = Number of Contact Injuries + Number of Non-contact Injuries
Number of Any/All Injuries = Number of Game Injuries + Number of Practice Injuries
CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback

3.3 ACUTE:CHRONIC WORKLOAD RATIO

3.3.1 ACUTE:CHRONIC WORKLOAD RATIOS AND PHASES OF THE SEASON

When analyzing ACWR by phases of the season, there was no significant difference in acute:chronic workload ratio values between the 1st and 2nd phases of the season, p = 0.159, displayed in Table 4. Further investigating each phase individually by season, there was no effect of phase of season on the ACWR, $F(3,417) = 1.737$, $p = 0.159$. As seen in Table 5 and Figure 5, Phase 2 of the 2019 season did display the greatest mean ACWR (1.01 ± 0.27) when compared to the other three phases but was not statistically significant.

Table 4 Acute:Chronic Workload Ratios by Phase of Season

Phase	N	ACWR Weeks	Mean ± SD		Median	IQR (1st Q, 3rd Q)	
1	33	162	0.95	0.26	0.95	0.80	1.10
2	33	259	0.98	0.30	0.99	0.80	1.16
					***p*-value (Mann-Whitney U-Test) =** 0.159		

Table 5 Acute:Chronic Workload Ratios by Phase of the Season per Season

Phase ID	N	ACWR Weeks	Mean ± SD		Median	IQR (1st Q, 3rd Q)	
1st Half 2018	22	80	0.95	0.28	0.96	0.81	1.11
2nd Half 2018	22	111	0.93	0.32	0.95	0.73	1.15
1st Half 2019	23	82	0.95	0.24	0.94	0.79	1.09
2nd Half 2019	23	148	1.01	0.27	1.00	0.86	1.17
					***p*-value (1-Way ANOVA) =** 0.159		

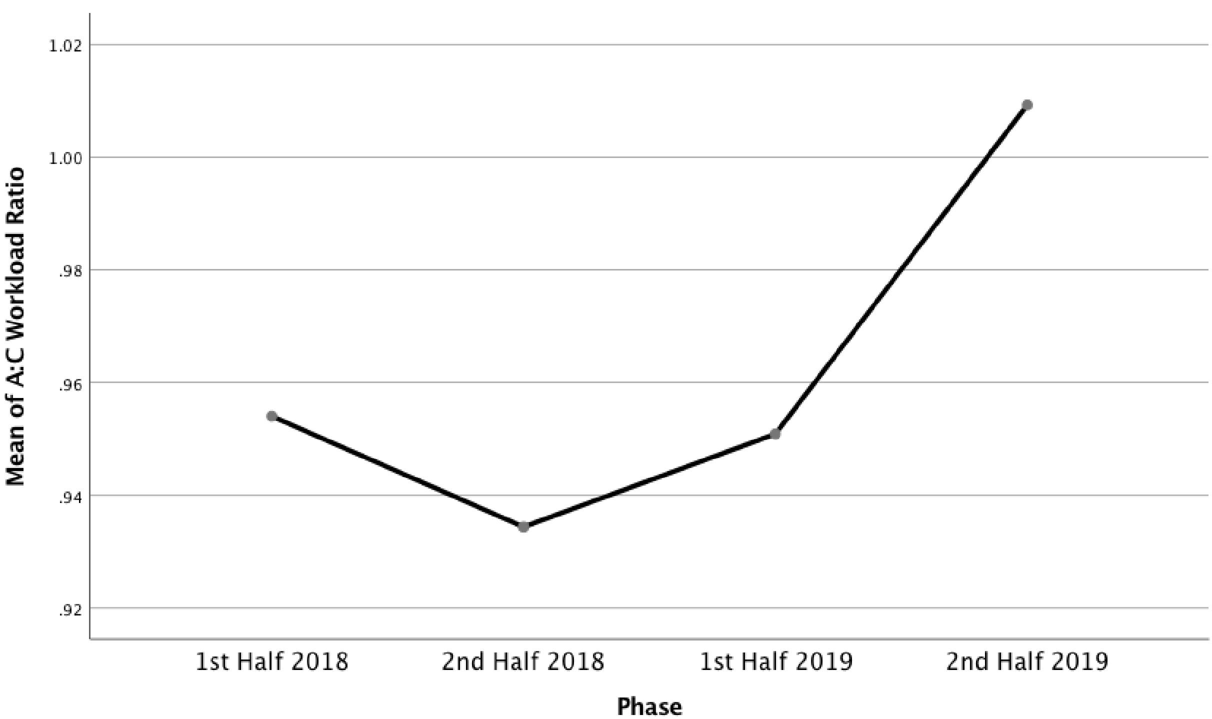

Figure 5 Mean Acute:Chronic Workload Ratios by Phase of the Season per Season

3.3.2 ACUTE:CHRONIC WORKLOAD RATIOS AND PLAYER POSITION

There was no statistically significant difference between ACWR among the 5 positions over the course of the two competitive seasons, $\chi^2(4) = 1.303$, $p = 0.861$. Results are displayed in Table 6. As seen in Figure 6, wingbacks (WB) marginally displayed the highest mean ACWR values over the two competitive seasons.

Table 6 Acute:Chronic Workload Ratios by Player Position

Player Position	N	ACWR Weeks	Mean ± SD		Median	IQR (1st Q, 3rd Q)	
CB	8	90	0.9506	0.2642	0.9507	0.7565	1.1439
CM	8	104	0.9817	0.2650	0.9754	0.8505	1.1381
F	4	48	0.9790	0.3133	0.9823	0.8303	1.1695
W	7	97	0.9479	0.3217	0.9832	0.7428	1.1515
WB	6	82	0.9853	0.2651	0.9723	0.8267	1.1405
					***p*-value (Kruskal-Wallis Test) =** 0.861		

CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback
N = # of Subjects

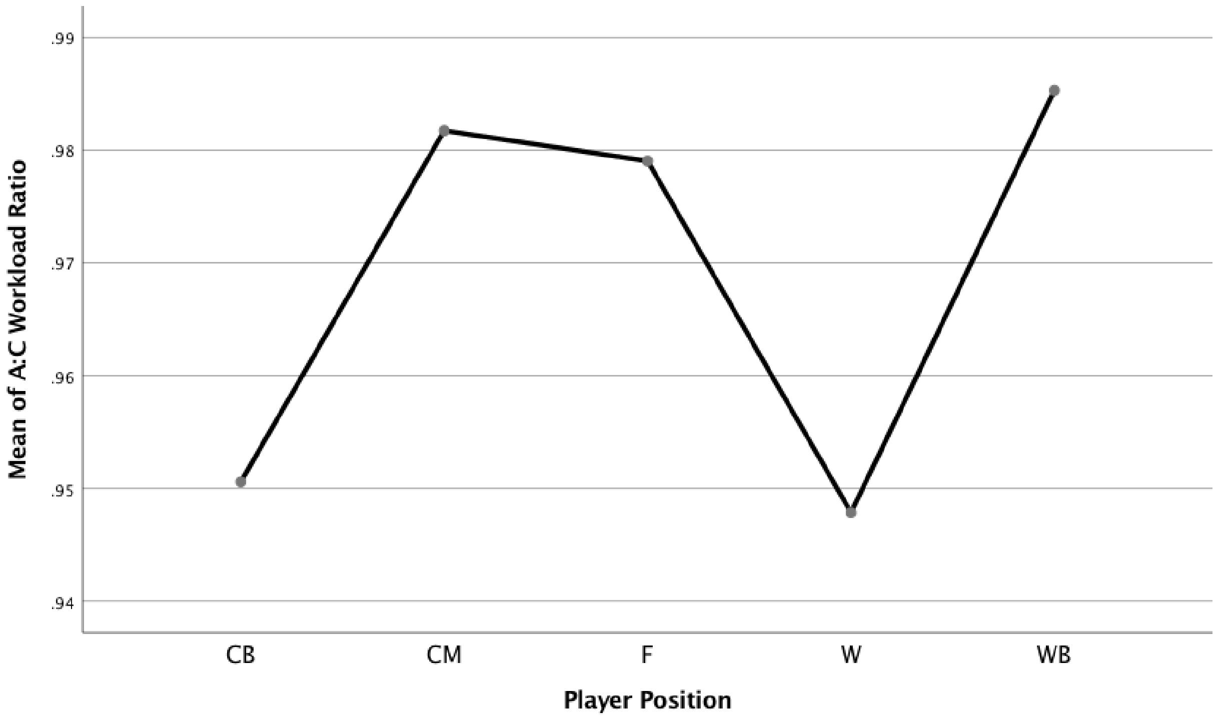

Figure 6 Mean Acute:Chronic Workload Ratios by Player Position

CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback

3.4 INJURY OCCURRENCE

3.4.1 INJURY OCCURRENCE AND PHASES OF THE SEASON

Injury occurrence was analyzed on a subject by subject case over the course of the two seasons creating a cumulative total of 45 subjects for analysis. Among any/all injuries during the 2018 season, McNemar's test showed that the percentage of injured athletes in phase 1 (9/22 = 40.9%) was not significantly different from the proportion of injured athletes in phase 2 (8/22 = 36.4%), $p = 1.000$. No statistically significant difference was noted between phases 1 and 2 when further investigating injury classifications of contact, non-contact, game, and practice during the 2018 season. Results are displayed in Table 7. As seen in Table 8, no statistically significant difference was noted between phase 1 and 2 among all injury classifications.

Table 7 Injury Occurrence by Phase of Season During 2018 Season

Injury Classification	**Phase 1**	**Phase 2**	***p*-value (McNemar Test) =**
Any/All Injuries	9/22 = 40.9%	8/22 = 36.4%	1.000
Contact Injuries	4/22 = 18.2%	3/22 = 13.6%	1.000
Non-contact Injuries	6/22 = 27.3%	6/22 = 27.3%	1.000
Game Injuries	4/22 = 18.2%	2/22 = 9.1%	0.687
Practice Injuries	5/22 = 22.7%	7/22 = 31.8%	0.687

Table 8 Injury Occurrence by Phase of Season During 2019 Season

Injury Classification	**Phase 1**	**Phase 2**	***p*-value (McNemar Test) =**
Any/All Injuries	10/23 = 43.5%	8/23 = 34.8%	0.754
Contact Injuries	5/23 = 21.7%	5/23 = 21.7%	1.000
Non-contact Injuries	5/23 = 21.7%	3/23 = 13.0%	0.727
Game Injuries	5/23 = 21.7%	7/23 = 30.4%	0.727
Practice Injuries	5/23 = 21.7%	1/23 = 4.3%	0.219

3.4.2 INJURY OCCURRENCE AND PLAYER POSITION

During the 2018 season, there was no association between occurrence of any/all injuries and player position, $p = .096$. However, when further investigating the injury classifications in the 2018 season, there was a statistically significant association between player position and non-contact injuries, $p = 0.002$, as well as practice injuries, $p < 0.001$ seen in Table 9. This association was seen to be linked to the large proportion of wingers (5/5 = 100.0%) and wingbacks (4/5 = 80.0%) sustaining these injury types when compared to the other positions. Displayed in Table 10, no significant association was identified between any of the injury occurrence characteristics and player position when analyzing the 2019 season. Total occurrence of injury by player position is noted in Table 11.

Table 9 Injury Occurrence by Player Position During 2018 Season

Injury Classification	**CB**	**CM**	**F**	**W**	**WB**	***p*-value (Fishers Exact test) =**
Any/All Injuries	1/5 = 20.0%	2/5 = 40.0%	1/2 = 50.0%	5/5 = 100.0%	4/5 = 80.0%	0.096
Contact Injuries	1/5 = 20.0%	2/5 = 40.0%	1/2 = 50.0%	0/5 = 00.0%	3/5 = 60.0%	0.396
Non-contact Injuries	0/5 = 00.0%	1/5 = 20.0%	0/2 = 00.0%	5/5 = 100.0%	4/5 = 80.0%	*0.002
Game Injuries	1/5 = 20.0%	2/5 = 40.0%	1/2 = 50.0%	1/5 = 20.0%	1/5 = 20.0%	1.000
Practice Injuries	0/5 = 00.0%	0/5 = 00.0%	0/2 = 00.0%	5/5 = 100.0%	4/5 = 80.0%	*<0.001

CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback

Table 10 Injury Occurrence by Player Position During 2019 Season

Injury Classification	**CB**	**CM**	**F**	**W**	**WB**	***p*-value (Fishers Exact test) =**
Any/All Injuries	3/4 = 75.0%	2/6 = 33.3%	3/3 = 100.0%	3/6 = 50.0%	3/4 = 75.0%	0.390
Contact Injuries	2/4 = 50.0%	1/6 = 16.7%	1/3 = 33.3%	3/6 = 50.0%	2/4 = 50.0%	0.766
Non-contact Injuries	1/4 = 25.0%	2/6 = 33.3%	3/3 = 100.0%	1/6 = 16.7%	1/4 = 25.0%	0.203
Game Injuries	3/4 = 75.0%	1/6 = 16.7%	2/3 = 66.7%	2/6 = 33.3%	2/4 = 50.0%	0.422
Practice Injuries	0/4 = 0.00%	2/6 = 33.3%	2/3 = 66.7%	1/6 = 16.7%	1/4 = 25.0%	0.425

CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback

Table 11 Cumulative Injury Occurrence by Player Position Over Two Seasons

Injury Classification	CB	CM	F	W	WB
Any/All Injuries	4/9 = 44.4%	4/11 = 36.4%	4/5 = 80.0%	8/11 = 72.7%	7/9 = 77.8%
Contact Injuries	3/9 = 33.3%	3/11 = 27.3%	2/5 = 40.0%	3/11 = 27.3%	5/9 = 55.5%
Non-contact Injuries	1/9 = 11.1%	3/11 = 27.3%	3/5 = 60.0%	6/11 = 54.5%	5/9 = 55.5%
Game Injuries	4/9 = 44.4%	3/11 = 27.3%	3/5 = 60.0%	3/11 = 27.3%	3/9 = 33.3%
Practice Injuries	0/9 = 0.00%	2/11 = 18.2%	2/5 = 40.0%	6/11 = 54.4%	5/9 = 55.5%

CB = Centerback, CM = Central Midfielder, F = Forward, W = Winger, WB = Wingback

3.5 ACUTE:CHRONIC WORKLOAD RATIO AND INJURY OCCURRENCE

Separate binary logistic regression analyses were run to assess the effect of ACWR values on each injury classification during the current week. The logistic regression model was statistically significant for any/all injuries, $\chi^2(1) = -1.494$, $p = 0.034$. Furthermore, significant findings were noted for non-contact injuries ($\chi^2(1) = -1.983$, $p = 0.041$) and practice injuries ($\chi^2(1) = -2.877$, $p = 0.006$). No statistically significant findings were found for contact injuries and game injuries. For comparison, further analysis was run on any/all injuries that occurred during the subsequent week and no statistical significance was seen in association to ACWR values.

Table 12 Simple Binary Logistic Regression Predicting the Likelihood of Injury Based on Acute:Chronic Workload Ratio

Injury Classification	**B**	**S.E**	***p*-value (Wald test)**	**O.R.**	**95% CI (Lower, Upper)**		***p*-value (Likelihood-ratio test)**
Any/All Injuries	-1.494	0.703	*0.034	0.224	0.057	0.891	*0.034
Contact Injuries	-0.876	0.978	0.370	0.416	0.061	2.831	0.373
Non-contact Injuries	-1.983	0.960	*0.039	0.138	0.021	0.904	*0.041
Game Injuries	-0.321	0.923	0.728	0.726	0.119	4.430	0.729
Practice Injuries	-2.877	1.037	*0.006	0.056	0.007	0.430	*0.006

B = Beta-coefficient, S.E. = Standard Error, O.R. = Odds Ratio

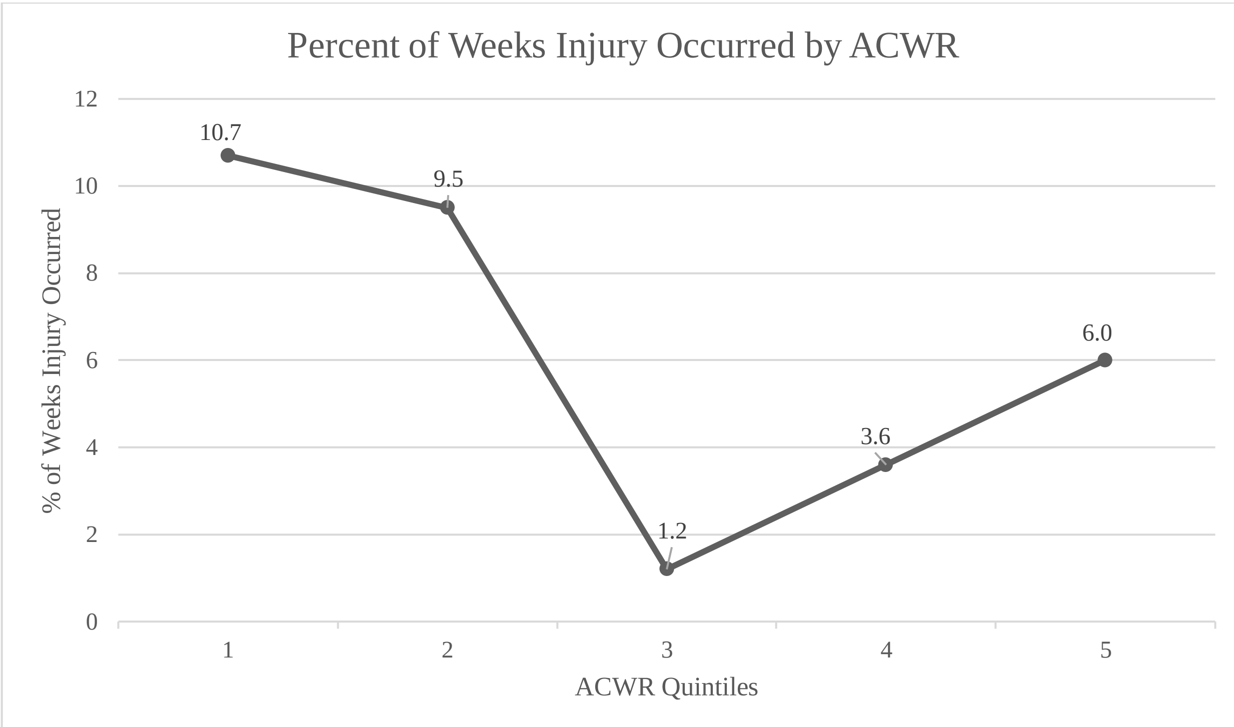

Figure 7 Percent of Weeks Injuries Occured by ACWR Split by Quintiles

Table 13 ACWR Quintile Ranges

Quintile	Range (Lowest ACWR – Highest ACWR)	
1	0.09176825	0.75663954
2	0.75663955	0.91634820
3	0.91634821	1.04060882
4	1.04060883	1.17861028
5	1.17861029	1.82533524

4.0 DISCUSSION

There are very few studies investigating the association between injury occurrence, external workload measurements, and other descriptive correlates. The purpose of this study was to examine the association between injury occurrence, the ACWR and other correlates throughout two competitive seasons in Division I collegiate soccer athletes. GPS and accelerometer statistics along with injury data was pulled retrospectively from 33 NCAA Division I male soccer athletes at the University of Pittsburgh. Many statistical analyses were conducted including a binary logistical regression to examine the relationships between injury occurrence, the acute:chronic workload ratio, and other correlates including player position and phase of season.

It was hypothesized that the ACWR would have a dose-response relationship with likelihood of injury where an increase in ACWR would result in a greater likelihood. This hypothesis was rejected as a significant negative association was displayed when considering any/all injuries, non-contact injuries, and practice injuries while no significant findings were noted in association to contact and game injuries. Furthermore, it was hypothesized that correlates such as phases of the season and player position would influence injury occurrence and ACWR values. Our hypotheses were mainly rejected, as most results did not demonstrate a significant relationship between the chosen correlates with injury occurrence and the ACWR. However, when analyzing the relationship between injury occurrence and player position, a statistically significant association was noted when investigating non-contact and practice injuries. Independent and dependent variables, research hypotheses, limitations, and future directions are discussed in the sections below.

4.1 FREQUENCY DISTRIBUTION OF INJURIES

Of the total 40 time-loss injuries over the course of the two competitive seasons, 20/40 injuries (50.0%) occurred during the 2018 season and 20 occurred during the 2019 season. When investigating injury mechanisms over the two seasons, 20 of the 40 injuries (20/40 = 50.0%) were a result of contact while the other half was due to non-contact. Although the collective sum accumulated from the two years were equal, values differed per year (2018; Contact: 8/40 = 20.0%, Non-contact: 12/40 = 30.0%, 2019; Contact: 12/40 = 30.0%, Non-contact: 8/40 = 20.0%). When classifying injury by setting, 22/40 or 55.0% of injuries were a result from game play while the remaining 18/40 (45%) occurred during practice. This finding is consistent with the previously mentioned studies where an increased injury incidence in games was displayed when compared to training.[36, 37, 76, 101, 116] Frequency varied again by year (2018; Game: 8/40 = 20.0%, Practice: 14/40 = 35.0%, 2019; Game: 12/40 = 30.0%, Practice: 6/40 = 15.0%).

When examining injury frequency by player position over the two years, wingbacks presented with the most injuries accounting for 12/40 or 30.0% of any/all injuries followed by wingers (10/40 = 25.0%), centerbacks (6/40 = 15.0%), central midfielders (6/40 = 15.0%), and forwards (6/40 = 15.0%). Among the 9 total active wingbacks over the two competitive seasons, only 7 sustained an injury during their active season. This finding indicates that each injured wingback averaged 1.7 injuries per active season. To the authors' knowledge, there are no current studies that displayed frequency distributions of injury in association to player position to identify categorical percentages.

4.2 ACUTE:CHRONIC WORKLOAD RATIO

The ACWR was assessed relative to phase of the season and player position to establish descriptive statistics for each group and to evaluate if differences existed between phases positions. When analyzing by phase over the two competitive seasons, there was no significant difference between ACWR values in the 1st and 2nd phase of the season, $p = 0.159$. Further investigating by individual season, there again was no effect on the ACWR, $F(3,417) = 1.737$, $p = 0.159$. These findings negate our hypothesis that ACWR will vary during phases of the season. As previously mentioned in the results, Phase 2 of the 2019 season displayed the greatest mean ACWR (1.01 ± 0.27) when compared to the other three phases but was not statistically significant. This finding is comparable to previous studies suggesting that the end of the season is when most high-intensity games are played and an increase in match congestion occurs.[38, 39] Subsequently, top level players are obligated to play more matches at the conclusion of the season when every game matters causing their workload values to increase.[39] To the authors knowledge, no previous studies have investigated phase of the season in relation to the ACWR as done in this study. However, it must be recognized that all mean ACWRs displayed in this study are located within what previous studies identify as the "sweet spot" where injury risk is low,[52] previously mentioned to range from 0.85 to 1.35.

One explanation for the lack of significance between the phases of the season could be the limited subject pool and lack of data in Phase 1 when compared to Phase 2. As the first 3 weeks of Phase 1 did not generate an ACWR, the number of available values differed greatly between Phase 1 (ACWR Weeks = 162) and Phase 2 (ACWR Weeks = 259). Furthermore, the initial few weeks of preseason tended to carry larger acute workloads as all subjects participated in two trainings per day on certain days. This may have affected the first ACWR values created from each season and further influenced the subsequent weeks values. In comparison, when analyzing Phase 2, the data from the final 3 weeks of Phase 1 allowed an ACWR to be generated immediately reducing the wait for an ACWR and increasing the available values.

The ACWR was further assessed by player position and was hypothesized that ACWR would vary by player position. Kruskal-Wallace test displayed no statistically significant difference between ACWR among the 5 positions over the course of the two competitive seasons, $\chi^2(4) = 1.303$, $p = 0.861$, rejecting our hypothesis. In total, wingbacks (WB) displayed the highest mean ACWR values over the two competitive seasons at 0.9853 ± 0.2651, followed by central midfielders (0.9817 ± 0.2650), forwards (0.9790 ± 3133), centerbacks (0.9506 ± 0.2642), and wingers (0.9479 ± 0.3217). While previous research has investigated the influence of player position on match performance parameters including high speed running and total distance,[17] no study to the authors' knowledge has investigated player position in relation to the ACWR. As evidenced by these findings, perhaps phase of season and player position are not as influential of correlates as believed in effecting ACWR.

4.3 INJURY OCCURRENCE

In attempt to preserve validity, injury occurrence was analyzed on a subject by subject basis and separated by competitive season due to some subjects being active in both seasons while others only participating in one season. Injury occurrence was identified if a subject sustained any injury that resulted in participation time lost and was further analyzed to assess correlation with phase of season and player position. In comparison to the injury frequency distributions displayed in the results section, lower injury occurrence values are seen due to some subjects sustaining multiple injuries during the same season. Among all four phases over the course of the two competitive seasons, Phase 1 of the 2019 season displayed the greatest injury occurrence with injuries among 10/23 subjects accounting for 43.5% of the subject population. This finding was similar to previous studies suggesting an increase in injury rates during the preseason and early part of the season at certain regions of the body.[38, 58, 61, 118] Hagglund et al.[61] presented an increased quadriceps muscle injury rate by 40% during the preseason compared to in-season. Mallo and Dellal[84] showed the highest incidence of sprains occurring during preseason and the beginning of the competitive season. Gouttebarge et al.[58] found players to be more at risk of non-acute groin injury in the first half of the season accounting for 82% of all cases. Although minor differences in the injury classification between Phase 1 and Phase 2 were noticed in the current study, there was no statistical significance between Phase 1 and 2 among all injury classifications during both seasons. Therefore, our hypothesis that injury occurrence would vary during phases of the season was rejected. These results agree with a meta-analysis by Doyle et al.,[32] where time of season and time in game had no influence of risk of ACL, groin, or hamstring injury. Woods et al.[118] also displayed an even distribution of injuries between preseason and competitive season.

When investigating player position, no significant association with occurrence of any/all injuries was displayed during the two seasons. However, as aforementioned in the results section, there was a statistically significant association between player position and non-contact injuries, as well as practice injuries, in the 2018 season. To the authors' knowledge, no previous studies have presented similar findings and results should be interpreted with caution as no further associations were noted in the following season. Our findings prove to be partially consistent with the results from previous studies where no significance was noted between injury occurrence and player position.[27, 84, 90, 112] As displayed in Table 11, forwards (4/5 = 80.0%) showed the greatest proportion of injuries when compared to other playing positions when data was combined between the two years. These results are consistent with previous literature findings where a trend towards an increased risk of injury in forwards was identified.[3, 5, 19, 30, 84, 112] In total, wingers displayed the most injury occurrences over the course of the two seasons with a total of 8 athletes sustaining an injury over the two competitive seasons. This details similar findings to those displayed by Raya-Gonzalez et al.,[104] who found wingers to present with increased prevalence of hamstring injuries. A systematic review by Della Villa[30] examined the effect of playing position on injury risk with two previous studies identifying an increased trend of injuries among midfielders.[20, 29, 90]

4.4 INJURY OCCURRENCE AND ACUTE:CHRONIC WORKLOAD RATIO

Of the 40 injuries that occurred over the course of two seasons, 14 injuries were further excluded from analysis due to injuries occurring outside the ability to calculate an ACWR. Inability to compute an ACWR was either due to injuries occurring during the first 3 weeks of the competitive season's start date or a succeeding injury ensuing less than 4 weeks from resumption of participation after an initial time loss injury. A binary logistic regression analysis was run individually to assess the effect of the ACWR on each injury classification. The logistic regression model was statistically significant for any/all injuries, $\chi^2(1) = -1.494$, $p < 0.034$, identifying a negative association between the variables of assessment. Therefore, periods of higher ACWR values were associated with a decreased likelihood of any/all injuries compared to periods of lower ACWR values resulting in an increased likelihood. ACWR values were then classified into quintile groups in ascending order by ranges seen in Table 13 and was further examined by the percentage of weeks an injury occurred in that range. Displayed in Figure 7, the same negative relationship was identified with an almost 'U'-shaped curve. This finding is partially consistent to Gabbett's[52] 'U'-shaped relationship between workload and injury where both inadequate and excessive workloads are associated with injury. However, the current study's findings lean more towards the impression that periods of lower ACWR values were associated with an increased likelihood of any/all injuries while periods of higher ACWR values resulted in a decreased likelihood. Furthermore, ACWR values from this study falling within the range that past studies consider to have the most resistance to injury (0.85-1.35),[54, 70, 71, 73] displayed a lessened likelihood of injury compared to values outside of the range. Gabbett and Ullah[57] identified a protective effect from soft-tissue injuries when covering extensive distances at low and moderate speeds. Furthermore, significant findings were noted among non-contact injuries and practice injuries. This may be a result of what previous studies have mentioned in respect to a higher frequency of contact injuries occurring in games over training. Research by Bowen et al.[16] displayed a greater contact injury incidence in match play (24.2/1000 hours) when compared to training (2.3/1000 hours) despite the much lower exposure to competition. Bowen et al.[16] further identified match play to account for 44% of all contact injuries. Thus, other confounders associated to the uncontrolled environment of match play may cause the subject to sustain an injury of contact nature aside from their control. Consequently, this study's results may identify that the ACWR may be more related to injuries that can potentially be prevented by modifications seen in training, and not acute injuries that are a result of contact or other spontaneous uncontrolled mechanisms of injury. However, as this is only a postulation, these findings should be interpreted with caution as association does not mean causation.

4.5 LIMITATIONS

This study has several limitations to be recognized. Although our sample of 33 individual subjects and 45 active subjects from the two competitive seasons coincided with subjects of some previous studies,[26, 71, 75, 85, 105] our study does not include a large sample size compared to others ranging from above 50-100 subjects.[42, 73, 88, 92] McCall et al.[88] conducted research from the UEFA Elite Club Injury Study where 171 players from 5 different teams were analyzed thus broadening the sample. Inclusion of different teams in a study allows factors that may further effect workload values, such as coaching philosophy, to be disseminated. Doing so may subsequently provide the best understanding of the results in the population. Our study only included one collegiate soccer team limiting our findings' ability to correspond to the entire soccer population. Due to the analysis only examining the two retrospective seasons from one team, injury data was scarce, and all injuries had to be taken into consideration.

Another cause of limited data was the duration of the subject season. As the competitive season for NCAA collegiate soccer is only 3 months in duration, data was limited when compared to previous studies investigating professional soccer seasons lasting 8-10 months.[75, 85, 88] Due to this confinement, phases of the season had to be separated into halves rather than preseason and competitive season periods. Furthermore, during the 1st phase of each season, missing ACWR data is evident over the first 3 weeks as ratios were generated at 1:4 weeks. If an athlete sustained an injury during that preseason period, the injury would be excluded as no

ACWR could be produced. This resulted in a further exclusion of 14 injuries when investigating Specific Aim 4, narrowing the data pool availability.

Human error is always a risk when conducting studies where subjects had control retrospectively over the implementation of the procedures. As previously mentioned, GPS/accelerometers were mandated to be worn during all training sessions and matches, however, a subject may have forgotten to place or turn the accelerometer on during a training or game. In these instances, the team's sports scientist monitoring live workloads or athletic trainer would remind the subject, however, no workload data would be recorded during that forgotten period.

Although we examined select variables considered to influence injury occurrence in soccer athletes, the multifactorial nature of injury will always prove to be a limitation for study. In our methodology, no internal workload values were utilized for analysis to assess the perceptual or physiological response to physical stress. Earlier studies used ratings of perceived exertion (RPE) as a measurement tool of ACWR in lieu of extracting data from GPS/accelerometers.[4, 42, 50, 63, 78, 85, 88, 94, 102, 105] Furthermore, RPE values display the individual's perception on the stressor, which may be considered as a more useful tool for injury prevention to some. Another internal workload value that has been measured to generate a workload value is heart rate (HR). Sekiguchi et al.[106] examined the relationship between HR variability and ACWR throughout one season in NCAA collegiate soccer with duration-created ACWR displaying significant prediction abilities. Other subjective measures including daily subject questionnaires that formulate a "readiness score" have now been incorporated into teams' daily screenings but no research has been conducted to date on its association to injury prediction. In respect to external training loads, numerous studies have identified significant findings with other variables such as duration,[26, 106] total distance covered,[16, 21, 26, 42, 57, 71, 73, 75, 92, 93, 106] high speed running/distance,[15, 70, 26, 42, 92] and accelerations/decelerations[15, 26, 70] to generate ACWR values and further analyze their association to injury. Our study aimed to examine the relationship between injury and workload values derived solely from PlayerLoads generated arbitrarily by Catapult Innovations software. Due to the lack of variables in consideration, results from this study should be interpreted with caution as the analysis is one-dimensional. In attempt to understand injury from a complex systems approach, this study would best be studied in a multifactorial manner.

Other confounding variables may include age and experience. Hagglund et al.[61] concluded that players above the mean age of 25.8 ± 4.5 years had an increased rate of calf injury by almost 2-fold with an odds ratio of 1.93. This study did consider subjects' age for demographic data but did not analyze further with injury occurrence. Another consideration would be the subjects' athletic experience at the level being investigated as it has previously been suggested that years of experience is correlated to an increase in decision-making abilities. Furthermore, decreased decision-making ability has been linked to increased injury risk.[74]

Lastly, a concept identified by Ehrmann et al.[34] can apply directly to our study's limitations. This was the notion that it is very common for athletes to play in pain or already injured without notifying team athletic trainers, doctors, or coaches. Subsequently, one may see players pacing themselves during training sessions and matches leading to variations in performance parameters from norm or further increase their risk of injury. As elite level athletes strive to compete as much as possible and avoid being removed from participation, this concept has become commonplace in soccer.[77]

4.6 FUTURE DIRECTIONS

Future research examining injury occurrence and the workload values should explore many adaptations of the current study. Firstly, the incorporation of numerous different teams providing more groups of subjects can be utilized in future studies. The subjects arising from the Division I collegiate team in the current study aimed to be generalizable to a young, elite soccer population. An increase in sample size will only benefit in understanding the diversity seen among subjects in the soccer population. As previous studies have found that age may be associated to an increased injury risk in athletes, [7, 60, 66, 114] future studies can investigate injury occurrence and ACWR values among different age groups. Furthermore, as years of experience and participation level have been linked to better decision-making in athletics, [106] a broad range of athletes with different experience and levels can be considered for future testing. Additionally, as this study only investigated male subjects, further sex comparisons may be made as there are sex differences in injury occurrence and workload values.

When investigating injury occurrence and the ACWR, future research should consider grouping workload values into classifications from very-low to moderate to very-high in attempt to identify injury risk. Hulin et al.[73] displayed a similar methodology in which found higher individual workloads, both acute and chronic, to have either positive or negative influences on injury risk among elite rugby players when considered with ACWR. The results of Hulin et al[73] identified the importance of analyzing in conjunction with the ACWR values as concluded that considering acute and chronic workloads in isolation did not provide any consistent mode of prediction.

The method of ACWR generation can also be altered in future studies. In this study, the ACWR was derived from the arbitrary unit of measurement produced by Catapult Systems termed PlayerLoad. Aforementioned in the study limitations, ACWR has previously been generated by other workload variables such as RPE, duration, total distance covered, high speed distance, and accelerations/decelerations, and it may be valuable to assess numerous internal and external workload variables in association to injury occurrence. In addition to workload variables, incorporating data extracted from daily subjective questionnaires may provide even more beneficial information on trends in ACWR values and injury occurrence. With the supplement of daily subjective information from the athlete, abnormalities can be identified to detect chronic illnesses or injuries that may have otherwise been overlooked.

Future studies can investigate the interaction among variables and regularities that arise rather than analyzing each in isolation to the outcome. By doing so, patterns of relationships can be identified, and a better understanding of the multifactorial nature injury will be established.[13] Ultimately, this study's limitations present the importance of players to be managed on an individual basis with continued development of monitoring and regulating workload values.

4.7 CONCLUSION

Although the core hypotheses of this study were rejected, the results provide valuable information to the understanding of injury occurrence and the ACWR in an elite soccer population. To the authors' knowledge, this is the first study to examine the relationship between injury occurrence, the ACWR, and other correlates such as phase of season and player position in NCAA Division I collegiate soccer athletes. In conclusion, the majority of our hypotheses were not supported, as results did not demonstrate a significant association between the chosen correlates with injury occurrence and the ACWR. A statistically significant relationship between player position and non-contact injuries as well as practice injuries was noted, however, this only occurred during the 2018 competitive season and no consistency was seen in the following season. Furthemore, a significant association was displayed between the ACWR and any/all injuries, non-contact injuries, and practice injuries. Overall, this study may provide a foundation for future research in the area of injury, workload values, and other correlates across a multitude of different populations.

APPENDIX A. WEEKLY CLASSIFICATION

Table 14 Week Classification by Date, Season, and Phase

Week #	Dates	Season	Phase
1	8/8/18 - 8/14/18	1	1
2	8/15/18 - 8/21/18	1	1
3	8/22/18 - 8/28/18	1	1
4	8/29/18 - 9/4/18	1	1
5	9/5/18 - 9/11/18	1	1
6	9/12/18 - 9/18/18	1	1
7	9/19/18 - 9/25/18	1	1
8	9/26/18 - 10/2/18	1	2
9	10/3/18 - 10/9/18	1	2
10	10/10/18 - 10/16/18	1	2
11	10/17/18 - 10/23/18	1	2
12	10/24/18 - 10/30/18	1	2
13	10/31/18 - 11/6/18	1	2
14	8/14/19 - 8/20/19	2	1
15	8/21/19 - 8/27/19	2	1
16	8/28/19 - 9/3/19	2	1
17	9/4/19 - 9/10/19	2	1
18	9/11/19 - 9/17/19	2	1
19	9/18/19 - 9/24/19	2	1
20	9/25/19 - 10/1/19	2	1
21	10/2/19 - 10/8/19	2	2
22	10/9/19 - 10/15/19	2	2
23	10/16/19 - 10/22/19	2	2
24	10/23/19 - 10/29/19	2	2
25	10/30/19 - 11/5/19	2	2
26	11/6/19 - 11/12/19	2	2
27	11/13/19 - 11/19/19	2	2
28	11/20/19 - 11/26/19	2	2

APPENDIX B. INDIVIDUAL DEMOGRAPHIC DATA

Table 15 Individual Demographic Data

Subject ID	Position	Age	Height (in)	Weight (kg)
1	CM	18	69	73.482
2	WB	21	66	70.3068
3	CB	18	71	78.0179
4	F	23	71	75.2963
5	W	19	67	63.5029
6	WB	22	67	71.6676
7	WB	18	71	78.9251
8	F	19	69	78.9251
9	CM	19	69	68.0389
10	CB	20	70	74.8427
11	CM	19	70	76.6571
12	CM	21	68	71.6676
13	W	21	68	71.6676
14	CB	21	76	81.6466
15	CB	20	71	81.6466
16	WB	18	67	63.9565
17	W	19	69	75.2963
18	W	18	68	68.4924
19	W	19	68	69.8532
20	WB	18	69	63.5029
21	CM	18	69	78.0179
22	CB	23	75	81.6466
23	W	20	66	68.0389
24	CM	20	72	78.0179
25	WB	21	72	72.5748
26	F	19	71	76.2035
27	W	21	73	72.5748
28	F	18	70	68.946
29	CM	20	70	63.9565
30	CB	22	74	78.9251
31	CM	18	70	71.214
32	CB	18	68	74.3891
33	CB	20	74	73.9356

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